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Space Vehicle Approach Velocity Judgments Under Simulated Visual Space Conditions

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SUMMARY

Thirty-five volunteers responded when they first perceived an increase in apparent size of a collimated, two-dimensional image of an Orbiter vehicle. The test variables of interest included the presence of a fixed angular reticle within the field of view (FOV); three initial Orbiter distances; three constant Orbiter approach velocities corresponding to 1.6, 0.8, and 0.4% of the initial distance per second; and two background starfield velocities. It was found that (1) at each initial range, increasing approach velocity led to a significantly larger distance between the eye and Orbiter image at threshold; (2) including the fixed reticle in the FOV produced a significantly smaller distance between the eye and Orbiter image at threshold; and (3) increasing background star velocity during this judgment led to a significantly smaller distance between the eye and Orbiter image at threshold. The last two findings suggest that other detail within the FOV may compete for available attention which otherwise would be available for judging image expansion; thus, the target has to approach the observer nearer than otherwise if these details were present. These findings are discussed in relation to previous research and possible underlying mechanisms.

INTRODUCTION

NASA considers all extravehicular activity taking place within 1 km of Space Station as "Proximity Operations" (PROX-OPS), which includes routine Orbiter berthing/docking to the Station; cargo transfer to and from the Station; operations involving the mobile remote manipulator system, free flyer, and orbiting maneuvering vehicle; and astronauts using manned maneuvering units (Donahoo and Anderson, 1985). In short, PROX-OPS refers to a wide variety of dynamic trajectory management tasks that are carried out by one or more vehicles at the same time.

Astronauts will continue to rely upon direct visual contact with the target vehicle for conducting the majority of planned PROX-OPS. This viewing will occur under a wide variety of viewing conditions which include very high and low ambient luminance levels, a significant reduction in gravity, and an external visual world that is always moving (Chorvinsky et al., 1961; Hyman, 1963; Schmidt, 1964). Basic to all of these astronaut-controlled PROX-OPS are visual judgments of range and range rate in many different viewing directions through specially designed PROX-OPS windows (Haines, 1986). The ability to make such visual judgments is the subject of this paper.

The primary question raised here was whether visual sensitivity of an expanding image of a radially approaching target vehicle is influenced by various static and dynamic visual background detail, such as stars, and a stable, collimated head-up display (HUD) alignment reticle.

This question arose as a result of numerous people noticing that the stationary Orbiter vehicle image seen out the window seemed to be moving (1) in a direction opposite to the star field movement and also (2) *toward* the observer. The first illusion, known as *induced motion*, is a well-known phenomenon (Wallach, 1959). A stable alignment reticle in the field of view (FOV) and/or a display of target coordinates may be used to counteract its effects. It is the second effect that is of concern here since, if an illusion of radial motion also exists when the target actually is stationary, it is possible that the observer might initiate a braking thrust to try to counteract this illusory motion which would actually move the vehicle away and use more fuel.

A secondary question addressed here was based on the assumption that the radial motion illusion (2) would occur and could be reduced to acceptable levels by using appropriate HUD symbology fixed within the window's FOV.

Relatively little is known about the influence of stationary and/or moving detail within the observer's FOV upon judgments of target motion. No studies could be found in which the target moved directly toward or away from the observer in the presence of a star (or other patterned) background. Some information is available on target movement in the frontal plane.

Research on Frontal Plane Motion Employing Nonhomogeneous Fields

Several investigators have quantified the effect of nonhomogeneous (patterned) visual fields near the target being moved (Brandt et al., 1973; Brown, 1931; Harvey and Michon, 1974; Owen et al., 1981; and Tynan and Sekuler, 1982). In general, the presence of a fixed pattern behind the moving target produces significantly greater sensitivity to motion in the *frontal plane*. Other research done to quantify

sensitivity to target motion in the frontal plane in impoverished visual field conditions similar to those found in the space environment include that by Brissenden (1962) and by Brissenden and Lineberry (1962). Since these studies are not related to radial target motion, they will not be discussed here.

Research on Motion Perception Using Radial Target Movement

Several investigators have studied the perception of target movement toward and or away from the observer using dark and or homogeneous backgrounds (Baker and Steedman, 1961; Bridgman and Wade, 1953; Marmolin, 1973; Parker et al., 1964; Salvatore, 1964, 1972). Unfortunately, none of these earlier studies used a single target which was viewed within a window frame aperture with a realistic star field also present. Nevertheless, some knowledge can be gained from these studies.

Geometry of Motion in Depth Consider a rigid object that is radially approaching the observer along the line of sight (LOS) at a constant velocity. Figure 1 illustrates the basic geometry of this situation.

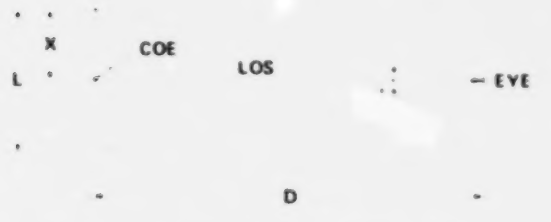

Figure 1. Geometry of object motion in depth.

The target's visual angle alpha (α) is given by equation (1) and its angular rate of change by equation (2). Referring to figure 1, D is the range and L is the particular target dimension of interest, in this case the nose to tail length of the Orbiter vehicle of 37.54 m (122 ft). The target's center of expansion (COE) lies on the LOS and all points making up the target will recede from the COE radially in accordance with equation (3). Here we assume that $X = L/2$. The relative velocity of the target traveling along the LOS is dD/dt.

$$\tan \alpha/2 = x/D \tag{1}$$

$$d\alpha/dt = 2(d(\alpha/2)/dt) \tag{2}$$

$$\alpha = 2 \arctan x/D \tag{3}$$

Because of the arctan function in equations (1) and (3), a constant linear approach velocity will result in a nonlinear angular expansion of the target image. At large values of D relative to X, the rate of change of α will not be large enough to be perceived. In this study three levels of initial range (D), and three range rates ($\dot{D}$), were quantified in the presence of various background viewing conditions. This radial approach represents a collision trajectory. The earliest visual detection of the increasing image size (or perhaps some other related dimension) represents the minimum change in separation distance between the observer and target that the observer is able to perceive correctly. Whether the observer will perceive the expansion of the target will be a function of (1) target distance (D), (2) time rate of change of D, and (3) viewing duration. The relationship between separation distance (D) and rate of closure is expressed as

$$\dot{D}\,D = [(1 + \tan^2 \alpha/2)(2 \tan \alpha/2)]\dot{\alpha} \tag{4}$$

Equation (4) predicts that the greatest sensitivity to rate of closure will occur at $\alpha = 90°$, which is what Pennington and Brissenden (1962) found.

Radial Movement Research Results Several studies on this subject have been conducted to date which include those of Baker and Steedman (1961), Bridgeman and Wade (1953), Parker et al. (1964), and Salvatore (1964). In all four studies the time to first detect a change in target size was the dependent variable. Other studies have been performed by Ittelson (1951), Marmolin (1973), and others in which the major focus was on background factors.

Baker and Steedman (1961) conducted several investigations in which a 3.5-in.-diam lamp, set at each of four luminances (0.001, 0.01, 0.1, and 1 ftL), was moved toward and away from the stationary observer on a track starting at each of six lamp diameters ranging from 0.025° to 1°. The visual background was homogeneously dark. In their first investigation a fixed velocity of 3.3 in./sec was used. During an approach trial the lamp was turned on at 25 ft from the observer (subtending 40′ arc diam). This produced an initial expansion rate of 0.5′ arc/sec. Six lamp-on durations ranging from 0.6 to 19.8 sec were used at each of the four luminances to control the total image expansion experience. Four observers were trained dark-adapted, and then presented with 25 trials during which they had to judge the direction of lamp motion (toward or away from them). A total of 2400 trials per observer were administered. No trials were given with no motion so that a 50% guessing rate was possible.

Baker and Steedman found that chance performance resulted for lamp travel distances under about 1% of the original 25 ft of travel, or 0.25 ft (expressing these results as a percent of total visual angle change is also referred to as a Weber ratio). For the two highest luminance conditions (0.1 and 1 ftL), accuracy increased rapidly from 50% correct

to a maximum 92% correct at only 7% of the maximum 25 ft of travel, or 1.75 ft. Performance was radically different for the two lowest luminance conditions (0.001 and 0.01 ftL). First, both curves were almost linear and parallel to each other, with the lower luminance condition producing lower accuracies by about 8%. Second, best performance was only about 85% correct for both conditions, although the lamp had to travel as much as 23% of the original 25 ft, or 5.75 ft, which suggests that target luminance plays a central role in such judgments. Third, a small but statistically significant bias (51.9%) in the "toward" direction was found and was explained as possibly due to the slightly greater visual angle change that occurs per unit time during an approach than during a receding trial. Fourth, the lamp had to travel a greater distance at each luminance when viewed with one eye in order to be correctly perceived. Fifth, for 75% correct judgment, percent distance traveled decreased with increasing luminance up to 0.1 ftL and, for binocular viewing, a further luminance increase to 1 ftL did not result in any further improvement. Finally, no learning effects were found.

In their second investigation Baker and Steedman (1961) presented the same lamp set to 1 ftL, but also set at each of four constant velocities (1.65, 3.3, 6.6, and 13.2-in./sec). These conditions resulted in a minimum percent size change of the lamp of 0.6% visual angle change per second and a maximum of 4.8%/sec. Minimum and maximum initial visual angle change was 0.25 and 2-min arc/sec.

They reported several findings. First, at all four velocities, increasing exposure duration produced a corresponding (almost linear) increase in the percent of observations that were correct, with maximum values of about 95%. Second, the slower the lamp movement the longer it had to be viewed before it could be correctly judged as having the correct direction of movement. Third, all four velocity condition curves were almost linear, parallel, and spaced equally apart on a log duration scale. This suggests that the visual mechanism which underlies this kind of judgment remains relatively constant over these velocities, which ranged over a factor of eight. Fourth, as before, a small response bias in the "toward" direction was found (50.7%). Fifth, binocular viewing produced smaller viewing durations to detect this radial movement at all four velocities. Indeed, the two curves were almost parallel and separated by about 0.6 sec at the standard 3.3-in./sec condition. Sixth, the higher the percent correct judgments that are going to be required of the observer, the more important velocity becomes. Thus, at a criterion of only 65%, the lamp has to move through only about 1.2% of its total travel for all four of the velocities tested. But requiring a criterion of 90 or 95% correct, the lamp's radial displacement is importantly influenced by its velocity. In general, velocity increases produce corresponding (almost linear) decreases in the percent of the distance through which the lamp must travel in order to be judged correctly. This finding is particularly important for space applications.

In Baker and Steedman's study, the lamp always began at a distance which produced a 40′ arc diam image (equivalent to viewing the Orbiter from the side at a range of 5442 ft). The angular rate of expansion was generally below visual threshold until the lamp's apparent diameter had changed by 2% (equivalent to about 0.8′ arc), which is less than normal static distance acuity and which disregards viewing duration.

In an earlier study Bridgman and Wade (1953) sat 10 observers (tested individually) in front of a projection screen on which was imaged a circular patch of illumination whose diameter was varied continuously in each direction. The edges of the 18-in.-diam aluminized screen were also visible and likely provided a valuable cue to this judgment. The observers were told that the image would change in size (and not in distance) and that they should respond as soon as they perceived an expansion or contraction in the projected patch of white illumination. They were told, "If it will help, you may think of the target as going away from you or coming toward you...remember, you must be quick and accurate." In some trials no change in patch diameter occurred. The six image rates of change were presented 10 times each in a random order both increasing and decreasing in size.

Bridgman and Wade's results were presented in terms of mean reaction time (seconds) plotted as a function of rate at which the image changed size (minutes of arc per second). They found that for image size change rates ranging from 0.7 to 4.2′/sec, the image had increased by about 3.3′ arc diam at the moment the observer responded. Similarly, the image had decreased from 4.4 to 6.3′ arc diam at threshold, indicating a slight bias in favor of judging the expanding image faster. They also reported that, for all rates of size change studied, increasing image diameter produces faster mean reaction times than does decreasing image diameter. Finally, the difference between the increasing and decreasing image diameter effect just noted lessens at higher rates of image size change. This study did not involve any binocular parallax cues to depth.

Salvatore (1964) presented his observers with an expanding or contracting horizontal line on the face of an oscilloscope and measured their reaction time to changes in length. Three initial line lengths were studied (1.43, 2.86, and 5.73°). Since the surrounding frame of the oscilloscope screen was visible, the judgments (very likely) would have been influenced by this stable surrounding frame of reference. He reported that for a line-to-background contrast of 0.63, an "expansion" Weber ratio of 12, 10, and 7% was found for the above three initial line lengths. A "contraction" Weber ratio of 14, 12, and 6% was found for the above three initial line lengths.

In all of the studies just reviewed (1) the target was a circular luminous area or a long thin line; (2) the background was homogeneously dark; (3) the viewing situation provided no actual cues to elicit binocular convergence or accommodative responses (except in Baker and Steedman, 1961); and

(4) there was never simultaneous imagery movement in two orthogonal directions within the field of view.

METHOD

Apparatus

The study was conducted in the NASA Ames Proximity Operations Research Mockup. This full-scale facility presents computer-generated, collimated, realistic, out-the-window scenes through three adjacent rectangular windows shown in figure 2.

The external scene was generated by an Evans and Sutherland Picture System II controlled by a PDP 11/60 digital computer. The imagery was updated at 30 Hz and completely filled the forward window, which measured 28° arc wide and 22° arc high. The realistic star field data base included all stars down to a visual magnitude of 5; there were about 35 to 40 stars visible at any moment. The dynamic target used was a nonsolid, "wire frame" image of the NASA Orbiter shown in figure 3(a). Stars could be seen moving vertically downward through the image. The Crew Optical Alignment Sight (COAS) consisted of a stationary vertical line with short horizontal tick marks at each degree arc (fig. 3(b)). The vertical length of this reticle was 18° and its lower end was coincident with the lower window frame.

The frontal plane angular translation rate of the star field had two levels. The slowest (0.1°/sec) corresponded to a 92-min orbital period while the fastest (0.3°/sec) corresponded to a 20 min orbital period, assuming the observer's vehicle pitches continuously throughout each revolution so as to keep the Earth below the vehicle.

The PROX-OPS mockup interior was illuminated by a dim red, fluorescent, diffuse source which produced an illuminance of approximately 15 ftc. The diffuse grey frames which surrounded each window were readily visible against the pitch black sky background and possessed a contrast (C)

Figure 2.– Window area of mockup.

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of 495 where $C = (Lt - Lb)/Lb$ (Lt = window frame luminance; Lb = sky luminance).

The observer responded by depressing a forefinger switch on a hand controller located on the instrument panel situated directly in front of the observer (fig. 2).

Procedure

Each observer was positioned approximately 18 in. behind the nearest edge of the window pane. The LOS was horizontal and penetrated the forward window at its geometric midpoint. The testing instructions were read by the observer. Then followed a 10-min adaptation period to the ambient illuminance. Unobtrusive, low-light-level TV cameras were used to help an experimenter monitor the observer's head position throughout testing. When viewed through the window, the Orbiter was seen from the top while it lay in the horizontal position, nose facing left (fig. 3). This was done to help reduce the influence of apparent motion due to so-called inherent motion properties of various target shapes (Smith, 1951).

Test Variables

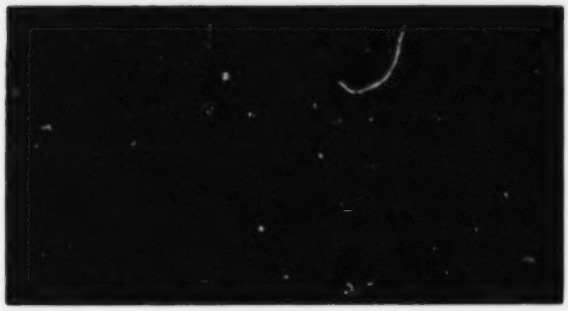
The experiment investigated the influence of the following variables: *background star rate* (two levels: 0.1 and 0.3°/sec); *presence of a stabilized COAS pattern* (two levels: on and off); *target approach velocity* (three levels: 1.6, 0.8, 0.4% of the initial range in meters per second); and *target initial position* (three levels: 1000, 400, 200 m).

Each observer was presented with all 36 conditions in random order. The presentation order of the three star velocity conditions and three target velocities was counterbalanced across all observers. There was a COAS present on one-half of all trials, while on the other half it was not present.

The beginning of the experiment was announced over an intercom. This helped the observer to be looking through the window at the target image. From 5-9 sec later the Orbiter image was automatically set in motion toward the observer.

Observers

Thirty-five volunteers (27 males, 8 females) took part in this study. Their mean age was 24.5 yr (SD = 8.8); they were experimenters, local college students, and staff members of the Aerospace Human Factors Research Division. All possessed corrected or uncorrected 20/20 distance acuity or better. Eight wore glasses (mean age = 29.6), 5 wore contact lenses (mean age = 19.4) while the remaining 22 wore no corrections (mean age = 25 yr). Four observers had "flown" the



(a) Wire frame image.

(b) COAS with image superimposed.

Figure 3.– External scene imagery used in study.

simulation before for various amounts of time ranging from 15 min to 6 hr.

RESULTS

The following topics are related to the test variables studied: initial target distance results, target approach velocity results, COAS results, star velocity results, and selected interactions. Wherever appropriate, the data were subjected to a mixed model ANOVA (Perlman, 1980) with observers considered to be a random variable and all others as within observer factors.

Initial Target Distance Results

Three initial target distances were investigated to vary the initial size of the retinal image. The fact that these distances would likely produce a large effect in the analysis make their comparison statistically of somewhat less interest. This ANOVA main effect was highly significant ($F = 5528$; 2/68; $p < 0.0001$). Table 1 presents the grand mean response data for each initial distance averaged across all of the other test conditions. Also included is the percent change in its visual angle (VA) subtended at the eye at threshold.

The percentage change in VA at threshold is approximately equivalent to the percentage change in distance for these three initial distances. Thus, traveling from 1000 to 400 m, the target would appear to expand by 149.8% of its initial length. The present grand mean data indicated that it had to expand by 140.1% of its initial VA. Likewise, traveling from 400 to 200 m, the target would appear to expand by 99.6% of its initial length while its VA actually expanded by 95.1% at threshold. Thus, the percentage increase in VA is slightly less than what would be expected on the basis of its geometric VA.

Target Approach Velocity Results

Three approach velocities were presented at each of the three distances of the target vehicle. These velocities were 1.6, 0.8, and 0.4% of the initial range in meters per second. It was found that the mean (SD) distance to the target at threshold for these three velocities, averaged across all other variables, was 502 (313), 486 (300), and 478 (303) m, respectively. These means are based on 420 responses each. Thus, the lower the approach velocity, the nearer the target had to be to be correctly perceived as approaching, a finding (1) statistically significant by ANOVA ($F = 19.2$; 2/68; $p < 0.0001$), and (2) in accord with findings from Baker and Steedman's second investigation (1961).

COAS Results

The mean (SD) distance of the Orbiter at threshold with the COAS off, averaged across all other variables, was 491.5 (310) m. When the COAS was visible, the threshold distance decreased significantly to 486.9 (301) m; ($F = 5.3$; 1/34; $p = 0.028$). Each mean is based on 630 responses.

Figure 4 illustrates the significant relationship between the Orbiter's approach velocity (curve labeled mean) and whether or not the COAS was visible. It is also to be noted that the Shuttle's approach could not be perceived as readily when the COAS was visible at each of the three approach velocities; i.e., the Orbiter had to approach closer to be perceived as having approached when the COAS was on as compared to when the COAS was off. This two-way interaction was not significant ($p = 0.37$) however.

Star Velocity Results

Mean distance at threshold to the Orbiter also was influenced by which star velocity was presented ($F = 11.8$; 1/34;

TABLE 1.- MEAN TARGET EXPANSION THRESHOLD RESULTS

	Initial target distance, m		
	200	400	1000
A. Mean distance at threshold	191.8 m	375.0 m	900.9 m
SD at threshold	(11)	(25)	(90)
B. Initial target VA	10° 43′ 21″	5° 22′ 23″	2° 9′ 2″
C. Mean VA at threshold	11° 10′ 41″	5° 43′ 50″	2° 23′ 12″
D. Initial $\dot{\alpha}$ (min arc/sec)	2.1	1.0	0.52
VA increase at threshold	32′ 40″	21′ 27″	14′ 10″
VA increase C vs B	4.25%	6.65%	11%

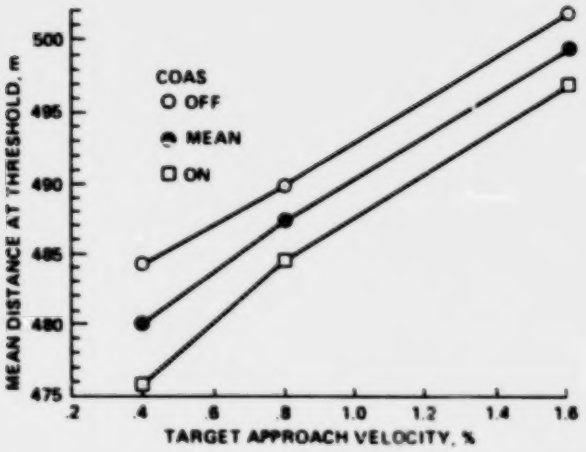


Figure 4.– Threshold distance to perceive the approaching Shuttle as a function of Shuttle velocity for the COAS on and off conditions.

$p < 0.002$). The mean (SD) distance of the Orbiter at threshold with stars moving at 0.1°/sec was 492.8 (307). With the stars moving at 0.3°/sec, the mean (SD) distance was 485.6 (303). These two means were based upon 630 responses each. It can be pointed out that the present instructions did not emphasize the fact that the stars would be traveling at different rates.

Selected Interaction Results

A number of interactions were of interest since they shed light on the interpretation of the main effects noted above.

Distance × *Velocity*– This two-way interaction was statistically significant ($F = 6.5$; 4/136; $p < 0.0001$). When plotted, this interaction showed that the three curves corresponding to the three initial ranges have almost identical slopes at the two lowest velocities (i.e., 0.4 and 0.8% of initial distance). However, the slope of the 1000-m distance curve increases between 0.8 and 1.6% approach rate as compared with the slopes of the curves for the 400- and 200-m distances (fig. 5). This suggests that it is the initial distance of the target (i.e., its initial retinal image size) that plays a more important role than approach velocity in determining when it will be perceived as approaching.

Distance × *COAS*– The ANOVA showed this two-way interaction to be significant ($F = 8.6$; 2/68; $p < 0.0001$). When plotted, this interaction was found to result from the fact that COAS on and off both produced equivalent distance judgments at threshold at 200 and 400 m, but the COAS on led to significantly earlier judgments at 1000 m. At such a large separation range in space, however, this difference would not be likely to be of practical significance.

Distance × *Star Velocity*– This two-way interaction also was found to be significant by ANOVA ($F = 3.5$; 2/68; $p = 0.033$). When plotted, this interaction resulted from the fact that the mean threshold distance increased almost linearly for the 0.3°/sec star velocity background condition over the 200- to 1000-m initial distances; however, the comparable curve for the 0.1°/sec star velocity background condition was not linear. The 1000-m distance condition contributed most to the change in slope. This finding suggests that the moving star background has a larger effect on smaller target images than on larger target images. No other factors or their interactions were found to be statistically significant.

Star Velocity × *COAS*– While not statistically significant, the mean distance to the Shuttle at approach threshold for the lowest star velocity (0.1°/sec) was 495 m with the COAS off and 491 m with the COAS on. Interestingly, at the higher star velocity (0.3°/sec), the corresponding values were 488 and 482 m, respectively. This tends to support an earlier conclusion based upon the COAS main effect that the COAS did provide a useful cue for judging the approaching Shuttle when the star background was moving faster. A follow-on stuuy is planned to investigate this effect in greater detail.

DISCUSSION

This study was based upon the hypothesis that rate of change of target image size can be used to determine the closure rate between two space vehicles. It may be mentioned that in actual space rendezvous operations the astronauts use

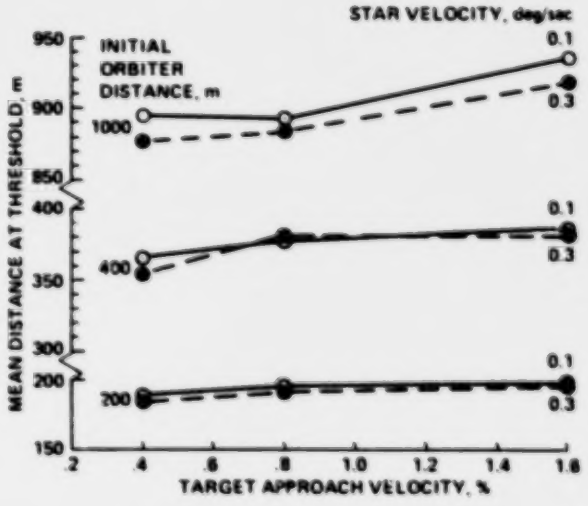


Figure 5.– Two-way interaction results between initial target distance and initial velocity.

the following rule of thumb with regard to approach velocities. They divide the instantaneous range to the approaching vehicle (in meters) by 100 and use that value in meters per second. This is equivalent to a Weber ratio of 1%.

It was found that the Orbiter image must expand by from 4 to 11% of its initial size to be correctly perceived as having enlarged (approached). It also was found that the larger the target's image is initially, the smaller the necessary amount of expansion at threshold. This also was found by Baker and Steedman (1961), Bridgman and Wade (1953), and Salvatore (1964). When the Weber ratio is plotted as a function of initial target size, Baker and Steedman (1961) reported that the resulting curve fell between a constant percentage ratio curve of about a 2% target size change and a constant angular increment of 0.8′ arc size change. That is, neither the Weber ratio nor constant angular increment accurately accounted for their findings. Figure 6 presents two empirically obtained curves from Investigation 3 of Baker and Steedman (solid lines labeled 90% correct and 75% correct), the "approach" data from Salvatore (1964) (short dashes), and the present data (long dashes). It should be remembered that the Baker and Steedman data represent the mean of both approach and recede observations whereas the present data are only for approaching trials, which might be expected to introduce a small directional bias in the "toward" direction due to reaction time and other factors. It is seen that percent distance traveled at threshold in all three studies decreases as the VA of the target increases.

Figure 6 shows that the present data are described by a straight line with a slope approximating that of a constant increment of about 21′ arc. This angular increment is over 20′ arc larger than that found by Baker and Steedman (1961), which may be due to the much larger targets employed. This is suggested because of the reasonably good agreement with Salvatore's data (1964) wherein he presented on an oscilloscope screen relatively long horizontal lines which expanded in length and which were similar in length to that of the present Orbiter's image.

This study also showed that a fixed reference line centered vertically in the FOV appears to somewhat inhibit judgments of the expanding image. The effect was small but statistically significant; the mean linear distance difference for the COAS on versus off was only 4.6 m. This distance difference has negligible importance in actual on-orbit operations. Nevertheless, this finding deserves further comment in light of previous research which showed the general utility of a fixed visual referent lying angularly near the moving target. At the nearest starting distance of 200 m, the Orbiter's image was 10° 43′ arc wide. This represents only 38.3% of the window's full 28° arc width. At the two succeedingly greater distances studied here, the Orbiter's initial width was 19.2 and 7.7% of the window's width. It is unlikely that the window's two vertical side frames contributed significantly to the present judgments. Earlier work in the author's laboratory on the vertical displacement threshold has shown that the helpful influence due to the spatial proximity of stable FOV references decreases rapidly beyond about 3 to 4° arc (Haines, 1984). Consequently, the presence of the window's side frames would not be expected to yield a significant aid in making this judgment. Similarly, the COAS reference should not provide an aid for judging the *horizontally expanding* length of the Orbiter's image. It was

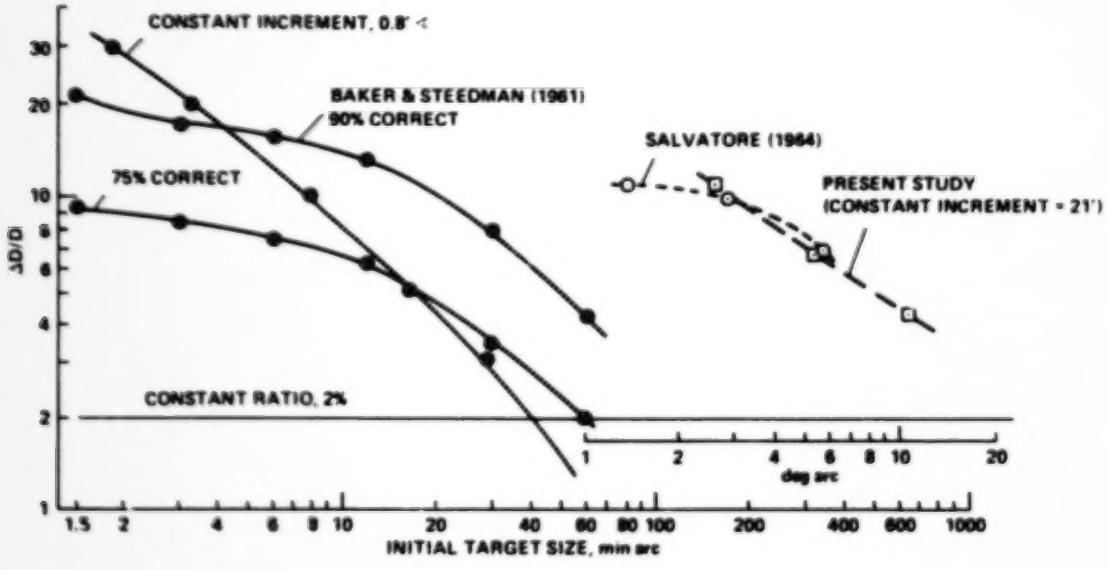


Figure 6.– Comparison of present data with previous studies.

expected that the vertical COAS would permit the observer to perceive the expanding image earlier, i.e., at a greater distance than without the COAS. This would be by virtue of relative movement between the expanding Orbiter image and the small, fixed tick marks at each degree along the COAS. This is not what was found. It is possible that the relative motion that was anticipated (between the fixed COAS ticks and the expanding image) was so small that other FOV detail, such as the moving stars, negated the effect. Follow-on studies are called for to develop and evaluate various COAS symbologies for different-shaped targets in various orientations relative to the COAS reference.

The statistically significant effect of background star motion raises an interesting question as to its cause. Indeed, proving that an effect exists is different from explaining why it occurs. Here it was found that the faster the background stars moved behind the approaching Orbiter, the nearer the Orbiter had to move before its image could be detected as having expanded. This effect is small and is seen in figure 5 at all three initial distances and at two of the three Orbiter velocities. It is theorized that this illusion of motion toward the observer was due to a direct competition for attention (to motion cues) between the stars and the Orbiter. People are accustomed to seeing the stars at night as being stable; aircraft and other aerial objects appear to move past them. Such relative motion is naturally attributed to the aircraft or object. In the present study the Orbiter definitely appeared to move opposite to the direction of motion of the slowly moving stars. This is the well-known induced-motion effect. Since it is common knowledge that spacecraft can move readily in any direction in space, it is possible for the present target to appear to be approaching the observer as well, particularly since all trials of the test include only approach movement. It should be mentioned that most observers noted the induced motion of the Orbiter in a direction opposite that of the background stars. Only a few observers, however, volunteered that the Orbiter seemed to be moving in any other direction. Apparently, the radial motion illusion is of small magnitude. A follow-on study is under way to further quantify this effect using a wider range of star velocities.

SUMMARY AND CONCLUSIONS

This investigation has shown that making judgments of a simulated space vehicle approaching on a direct, collision course with the observer will be influenced by numerous and somewhat subtle factors. These factors include initial separation distance and approach velocity of the target vehicle, the angular velocity of the background stars, and the presence of a fixed COAS reticle. Perhaps the most general applied conclusion that can be made is that unless and until the above factors are better understood, it will be wise to continue to use approach velocities lower than those used here in actual space operations. A second, related conclusion is that further research is needed to elucidate the precise influences of these viewing variables upon judgments of an Orbiter's approach. Studies are currently under way to more fully quantify the influence of a wider range of background star velocities than were presented here and also to quantify initial target sizes that are in the 30 to 130° arc range.

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16. Abstract

Thirty-five volunteers responded when they first perceived an increase in apparent size of a collimated, two-dimensional image of an Orbiter vehicle. The test variables of interest included the presence of a fixed angular reticle within the field of view (FOV); three initial Orbiter distances; three constant Orbiter approach velocities corresponding to 1.6, 0.8, and 0.4% of the initial distance per second; and two background starfield velocities. It was found that (1) at each initial range, increasing approach velocity led to a significantly larger distance between the eye and Orbiter image at threshold; (2) including the fixed reticle in the FOV produced a significantly smaller distance between the eye and Orbiter image at threshold; and (3) increasing background star velocity during this judgment led to a significantly smaller distance between the eye and Orbiter image at threshold. The last two findings suggest that other detail within the FOV may compete for available attention which otherwise would be available for judging image expansion; thus, the target has to approach the observer nearer than otherwise if these details were present. These findings are discussed in relation to previous research and possible underlying mechanisms.

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